The Lithium Tokamak eXperiment - LTX

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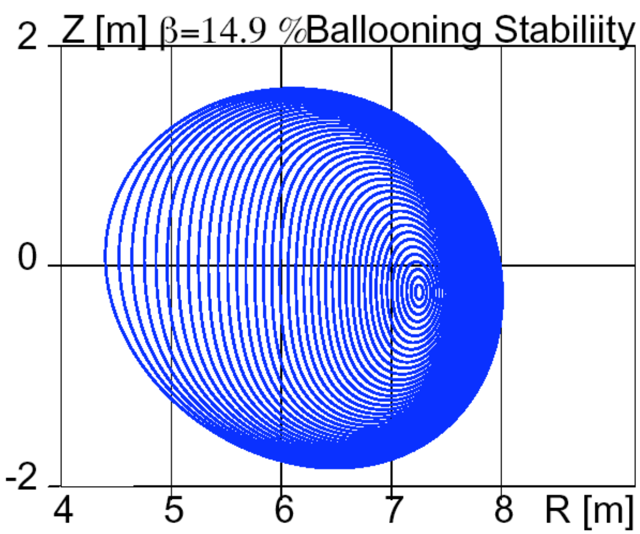
PFC meeting
17-20 November 2003
Oakbrook, Ilinois

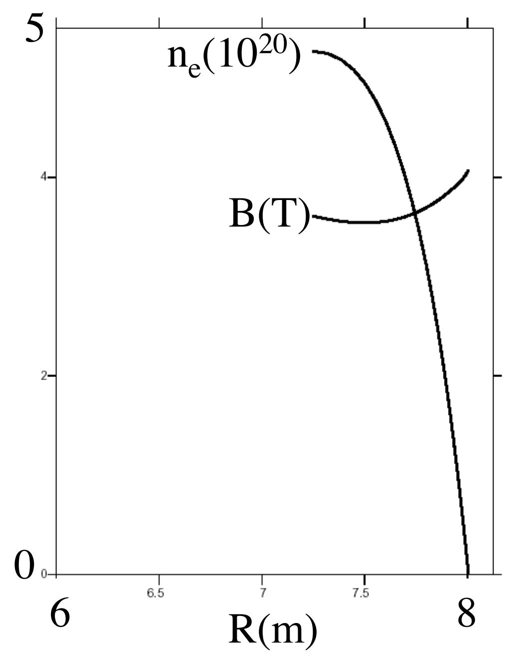
Introduction

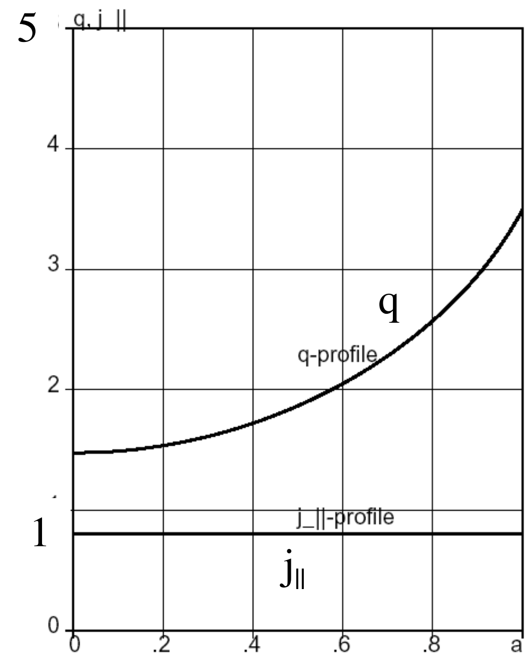
- The LTX proposal has been funded as a result of this years' ICC solicitation
  - Timeline was "stretched" to four years, but fully funded at the requested level
- LTX will be the first "new" machine in the U.S. dedicated to a PSI issue since ISX
- We are hoping that the ongoing interaction between the PFC community and CDX-U will continue with LTX, despite the change in funding source

Ultimate goal of the lithium tokamak: engineering simplicity in an attractive fusion reactor

- "Circular" tokamak equilibrium. A~4.
- "Neutral" stability to vertical displacements
- R~6m, a~2m, B=5T with flowing lithium walls
- P_{DT} = 4.5 GW
- Fully bootstrapped
  - No core or edge current drive
- Not sensitive to bootstrap "overdrive"
  - No need for current profile control
- Sustained only with high-field side gas/cryogen jets



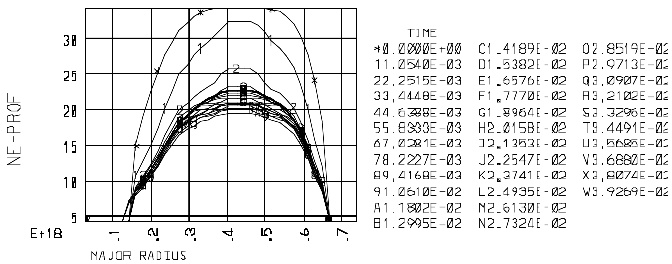


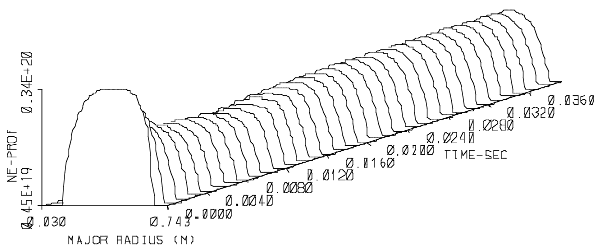


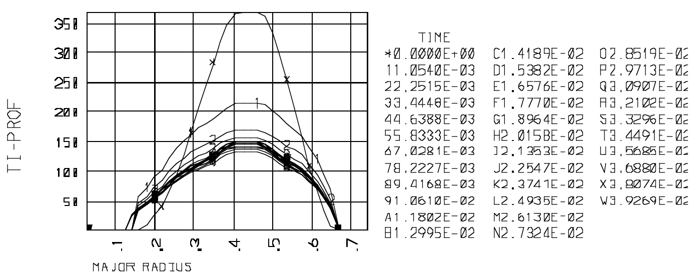
Plan for LTX

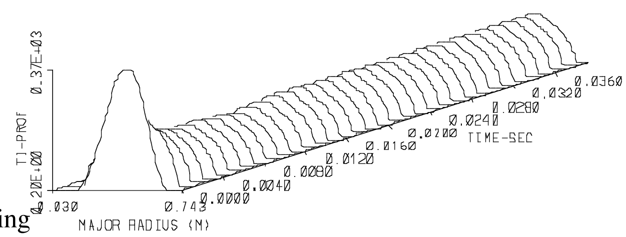
- Modify CDX-U to accomplish the LTX objectives
  - R=40 cm, a=26 cm, κ=1.55, B_T=4 kG, I_p <400 kA (50 msec flattop)
- Lithium wall technology: thin films
  - Recoated between discharges
  - Plasma-aligned, heated wall (tungsten sprayed, chromium plated copper shell)
  - Poloidal field, control system upgraded
- Core fueling
  - Multiple (8) pellet injector (ORNL separately funded)
  - Supersonic gas injector
  - Upgraded ohmic system, toroidal field to permit pellet sustainment
- Diagnostic upgrades
  - Improved Thomson scattering (edge)
  - Expanded magnetics for current profile reconstruction

TSC modeling for LTX







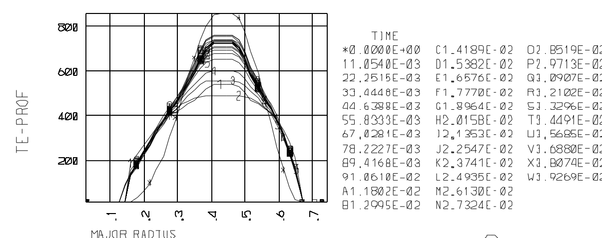


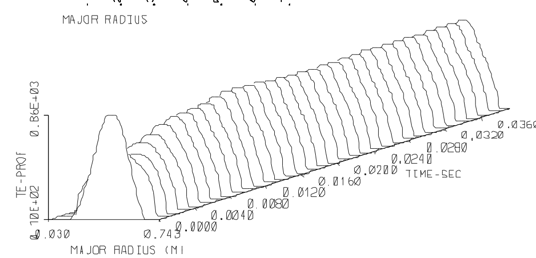
- Ohmic, high recycling

Table 2.1: Parameters used in TSC simulations of LTX discharge.

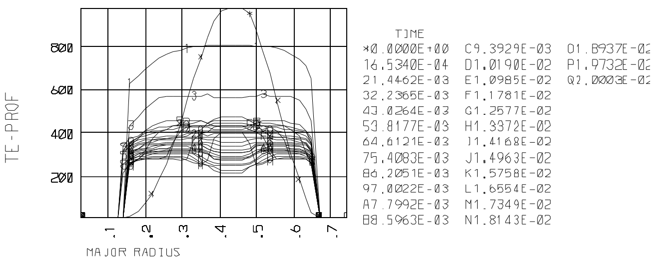
Major Radius	R_0	0.4 m
Minor Radius	a	0.26 m
Triangularity	□	0.2
Ellipticity	□	1.33
Plasma Current	I_P	250 kA
Toroidal Field	B_T	0.38 T
Simulation Time	t_{sim}	20 ms

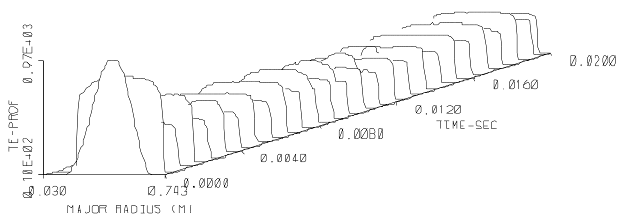
>GLF23 model for particle transport

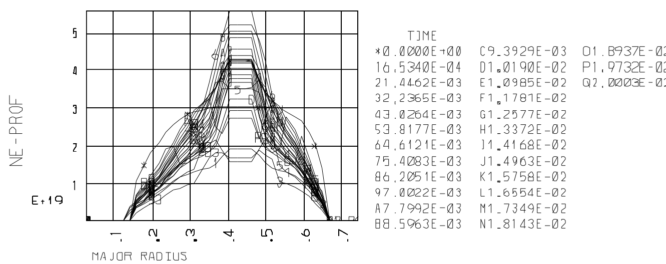


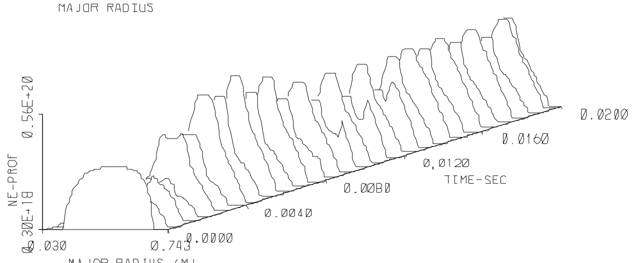


Modeling with TSC predicts that LTX will achieve flat electron temperatures *with no electron conduction losses*







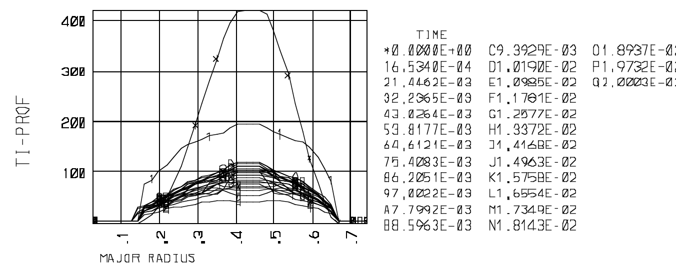


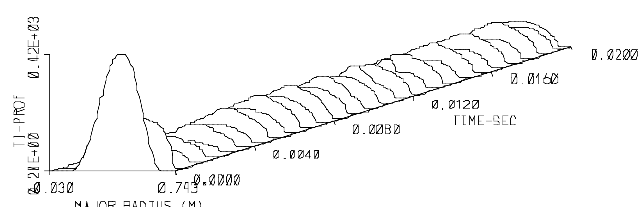
◆ Pellet-fueled, no recycling

Table 2.2: Comparison of Centrally-fueled and Edged-Fueled TSC simulations.

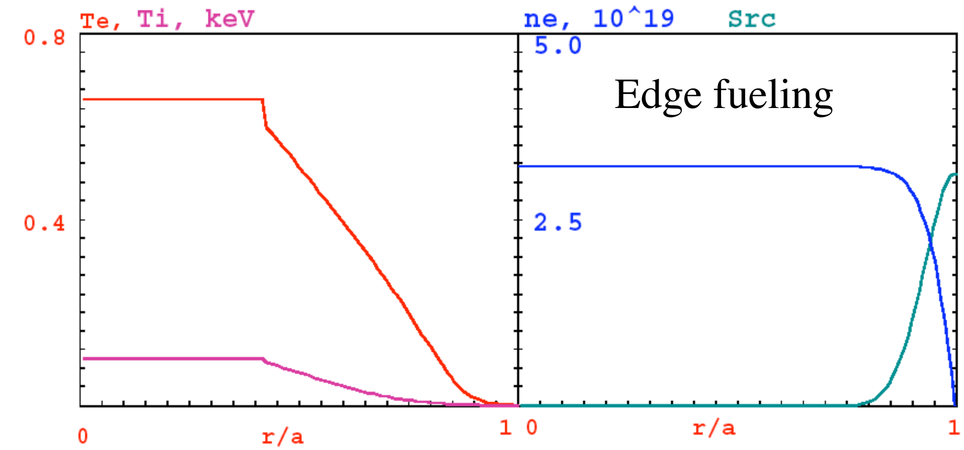
		Centrally-fueled	Edge-fueled
Line-averaged density	$<n_e>_L$	0.2-0.28 □ 10^{20} m^{-3}	0.16 □ 10^{20} m^{-3}
Central density	$n_e(0)$	0.5-7.5□ 10^{20} m^{-3}	0.20 □ 10^{20} m^{-3}
Internal energy	W	0.9 kJ	1.1 kJ
Internal inductance	ℓ_i	0.79	0.96
Central electron Temperature	Te(0)	200-410 eV	800 eV
Central Ion Temperature	Ti(0)	90-110 eV	150 eV
Peak-to-average Elec. Temp.	$Te(0)/<Te>_V$	0.9 – 1.5	2.2
Peak-to-average Ion Temp.	$Ti(0)/<Ti>_V$	1.5 – 2.7	1.9
Radius of q=1 surface	R(q=1)	0.11 m	0.15 m
Surface Loop Voltage	V_L	1.2 – 1.6 V	1.4 V
Convective electron energy transport	□$_e$	**1.00**	**0.075**
Convective ion energy transport	□$_i$	**0.67**	**0.075**

>Trapped electron modes are completely stable

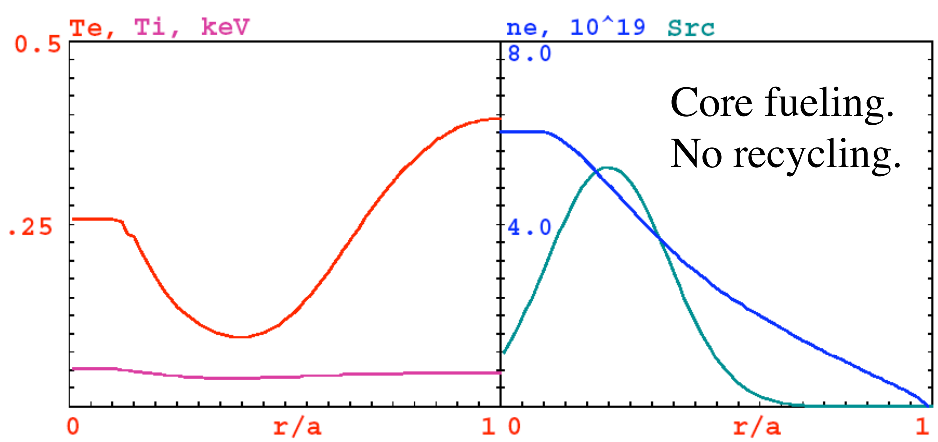


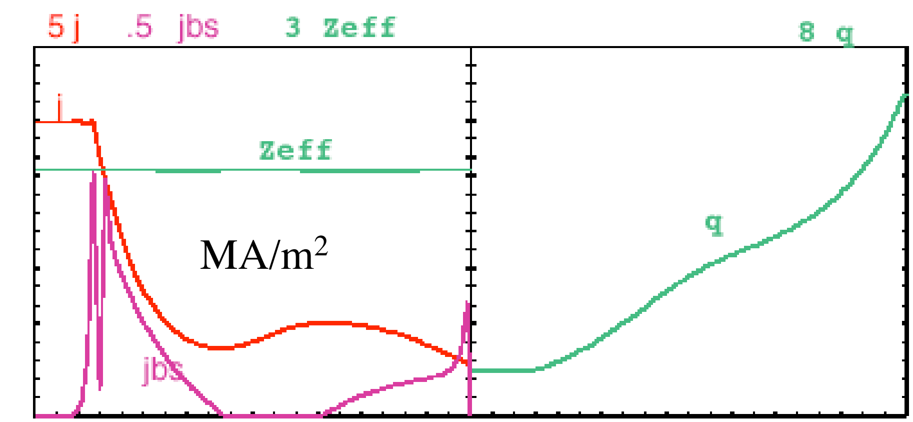


ASTRA modeling also indicates that an LTX-scale device can test the effects of core fueling with no recycling



- Model particle sources as shown
- Neoclassical transport
- Edge pedestal current predicted to be significant in low recycling case
  - Copper shell will provide stability





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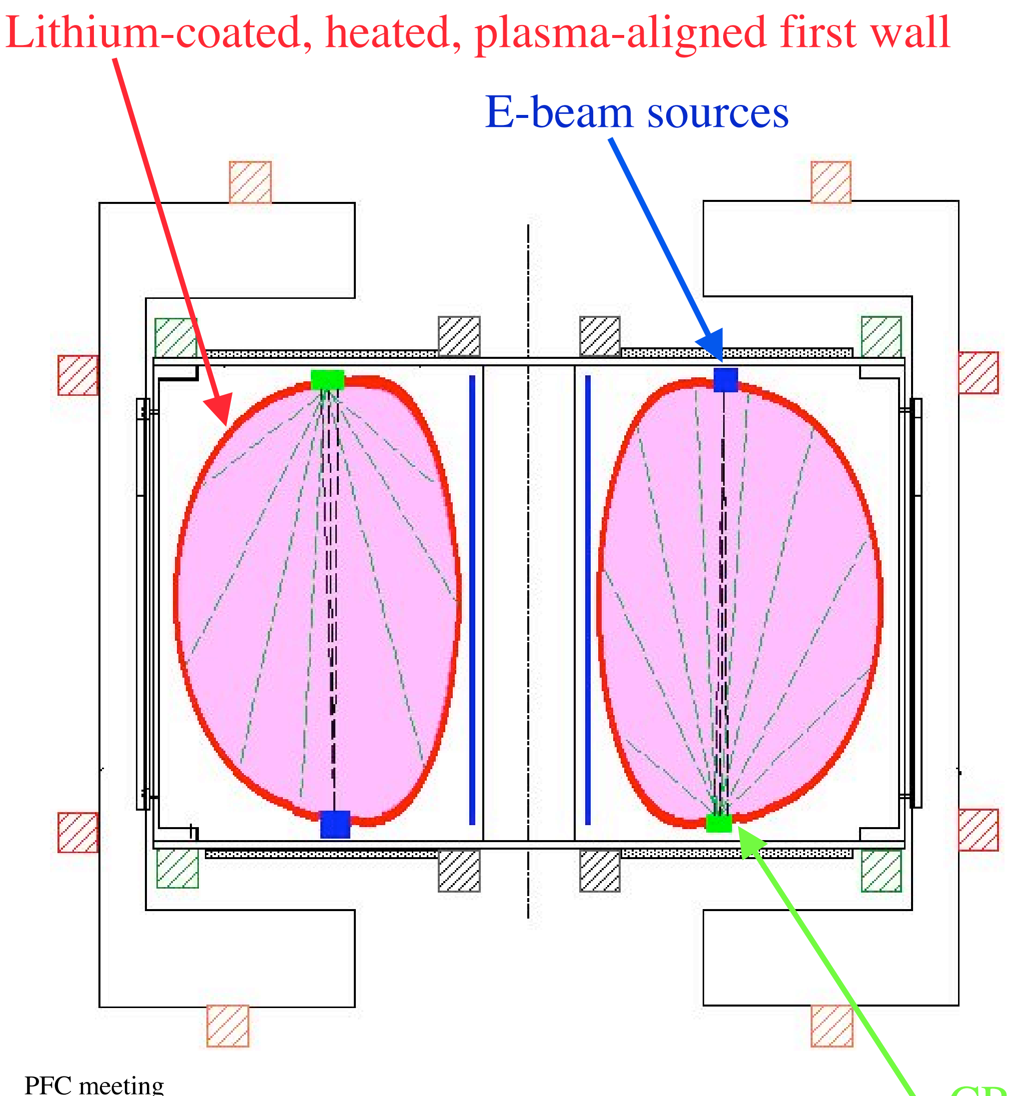
L. Zakharov

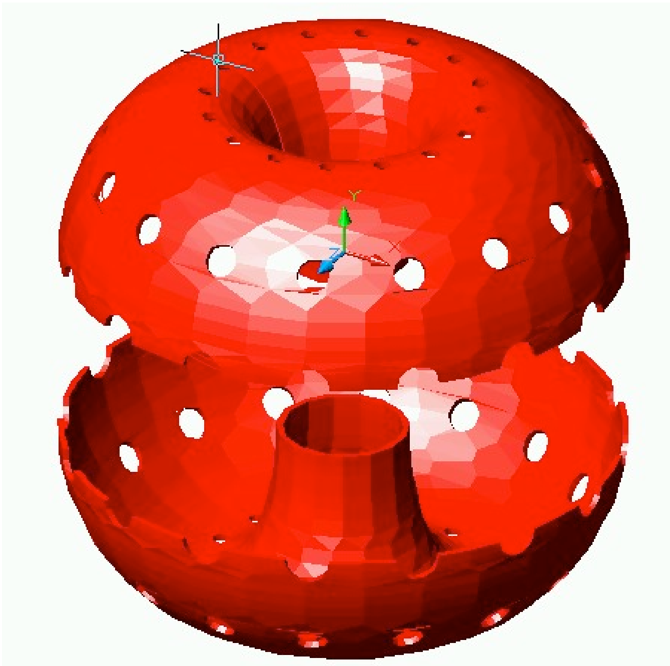
Lithium wall technology will use thin films

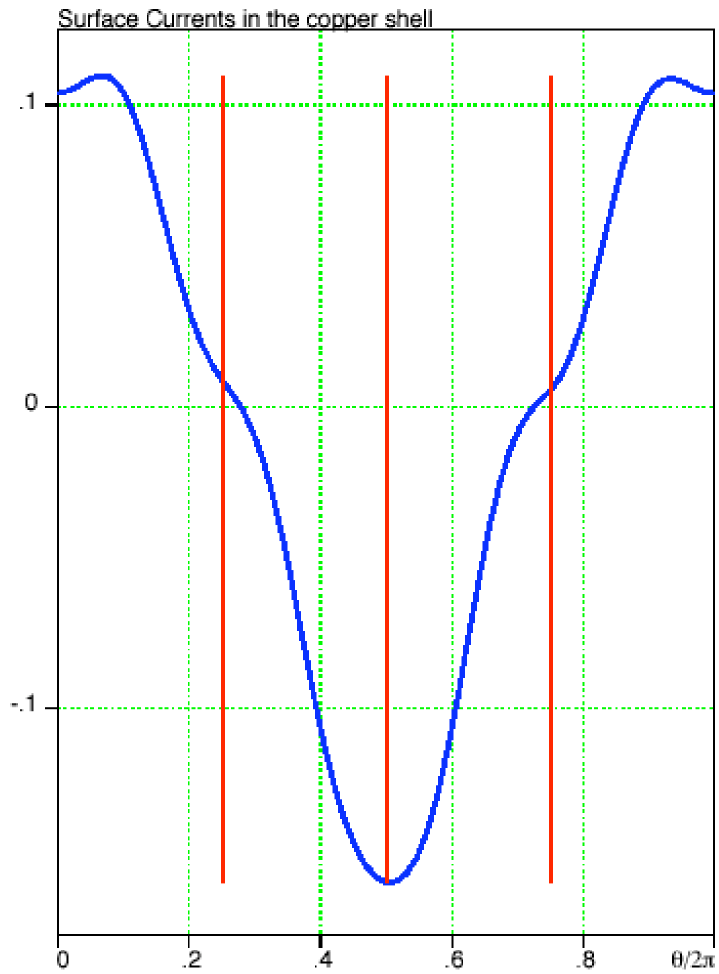


- Electron-beam deposition
  - 1000 Å coating applied between discharges
  - Fixed beam, lithium sources
  - 3 on top, 3 on bottom
- Wall temperature of 250-350 ^{o}C will keep lithium coating molten
- Heat-conducting copper shell
  - Maintain molten film
  - Contribute to stability
  - LCFS held conformal to ~ 1 cm tolerance with PF set
  - Test wall coupons are now at the sprayer

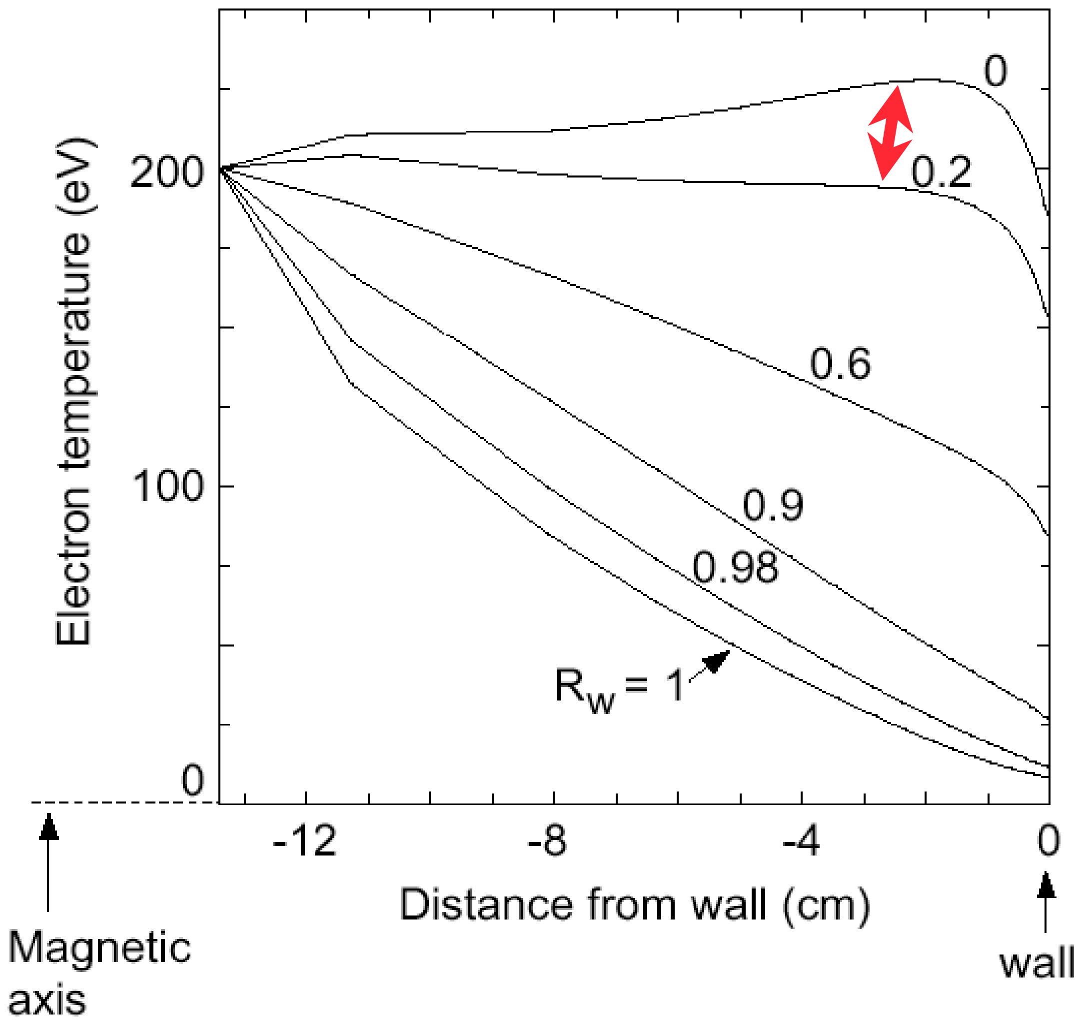
Conformal tungsten-sprayed, chromium plated cast copper shell will form first wall in LTX

- Shell will provide largest possible PFC surface area to minimize deuterium flux/unit area
- Uniform surface temperature with modest complement of heaters
- MHD stabilization of the "peeling" mode may be additional benefit





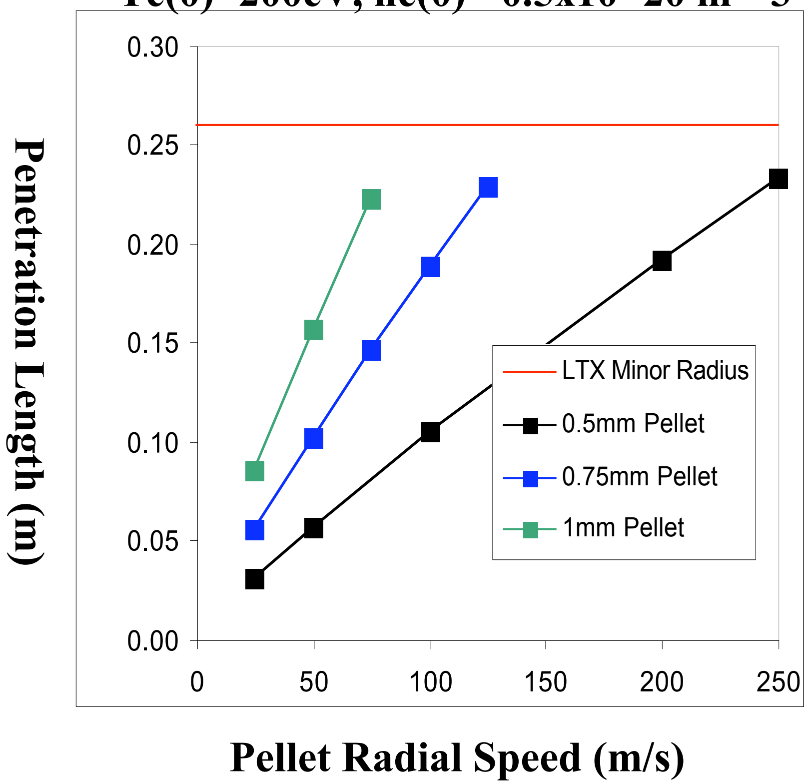
Target is ~10% recycling coefficient



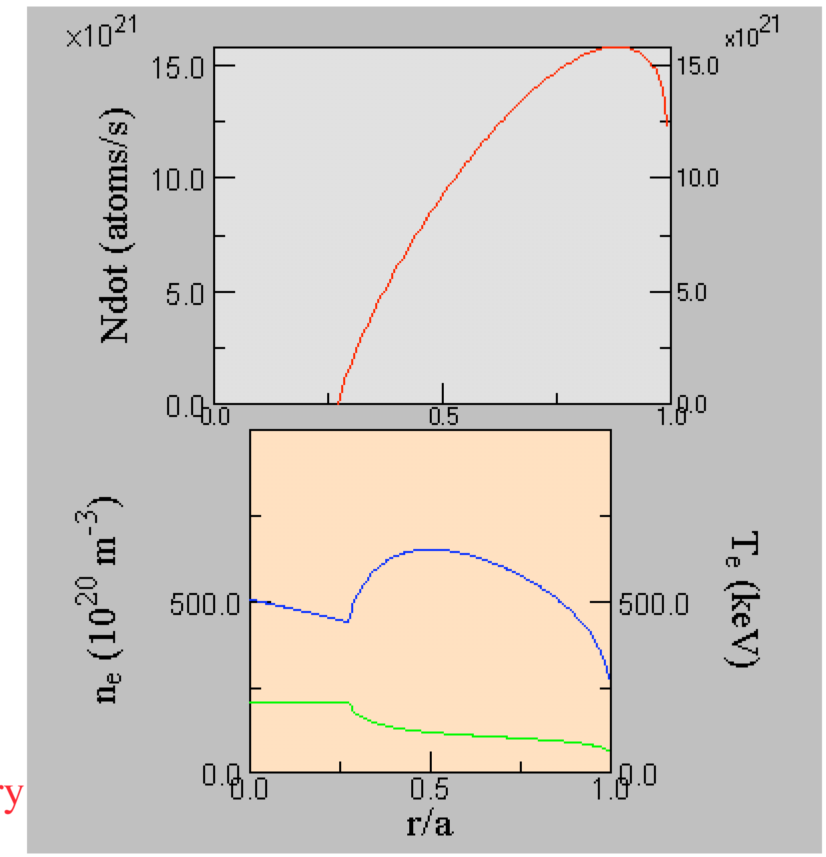
- UEDGE modeling (T. Rognlein)
  - Complements transport models (ASTRA)
- Liquid lithium shown experimentally to produce adequate recycling reduction
- CDX-U (with much more modest reduction) has already made preliminary observations of a change in L_i

ORNL has been funded to provide a pellet injector
Lead candidate now an 8 barrel version of a "suitcase" injector

Pellet Penetration as fn of Speed
Te(0)=200eV, ne(0)= 0.5x10^20 m^-3



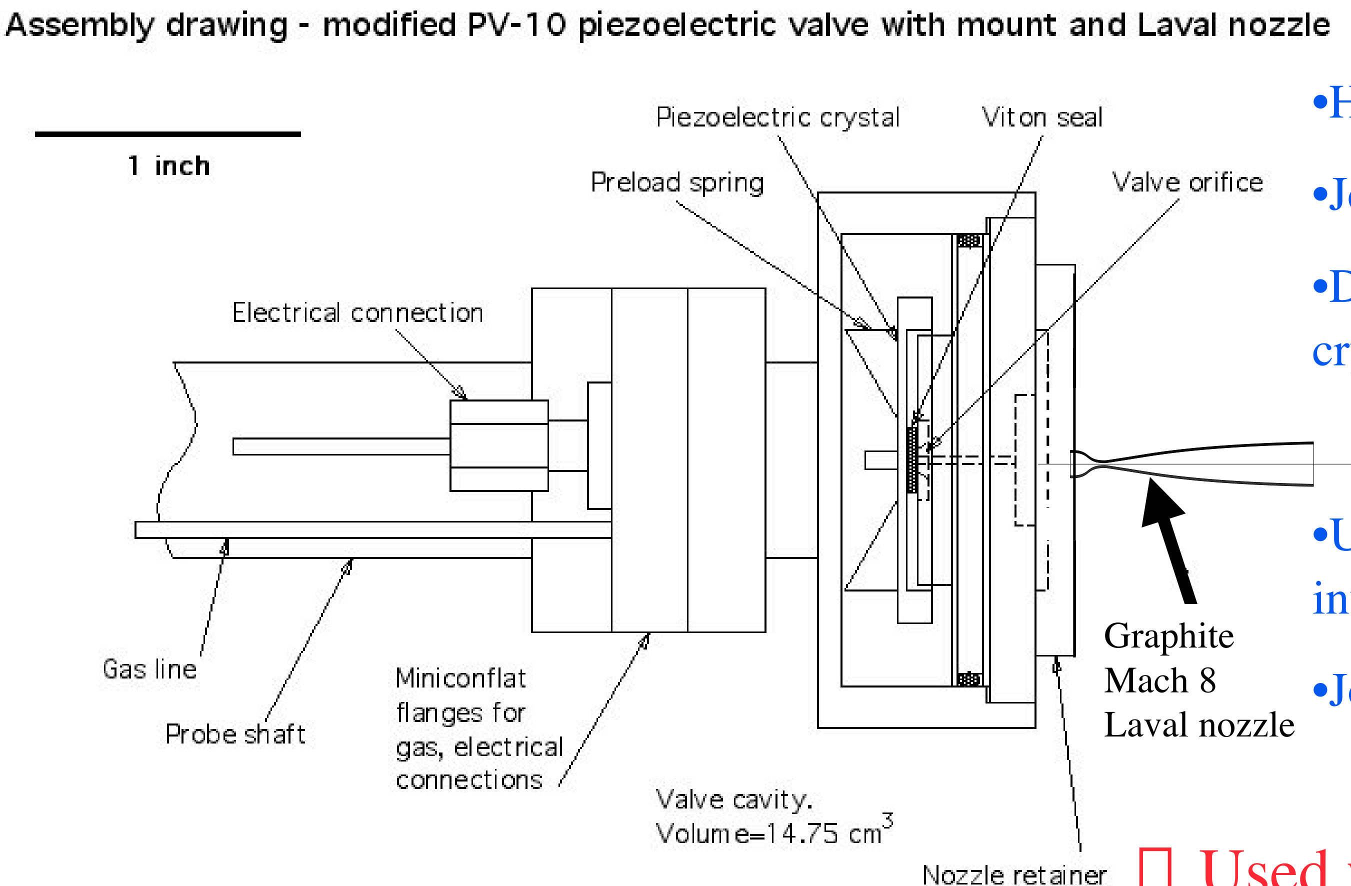
Te(0)=200eV, ne(0)= 0.5x10^20 m^-3
Cylindrical Pellet Diameter: 0.75 mm
Pellet Radial Speed: 100 m/s



- 0.5 - 1 mm pellets are stopped by the LTX plasma
- Particle content is 1/3 - 1/2 the LTX particle inventory

Pellet Model: ORNL Neutral Gas Shielding Model (also modeled in TSC)
(ORNL model made available by L. Baylor)

Novel supersonic gas injectors will complement pellet fueling



- High field side injection
- Jet diameter ~8 mm
- Designed to inject gas + crygenic liquid at Mach 6-8
  - ~2 km/sec
- Up to 1/2 the particle inventory in 1 msec
- Joint CDX-U/NSTX project
  - Test have begun

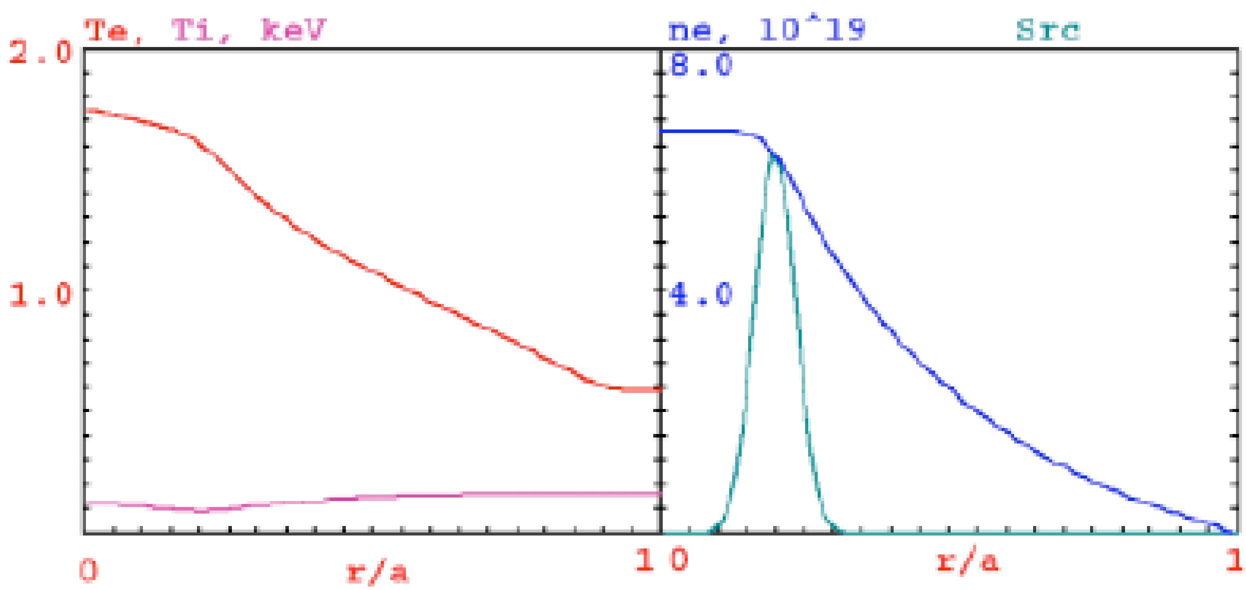
 Used with 20kW 14 GHz high-field side ECH for startup

Nozzle design scaled from working Mach 8 wind tunnel at Gaseous Dynamics Laboratory, Princeton University (A. Smits, M. Baumgartner)

G. Gettelfinger, H. Kugel, V. Soukhanovskii

A new technique - DHD fueling - will be tested

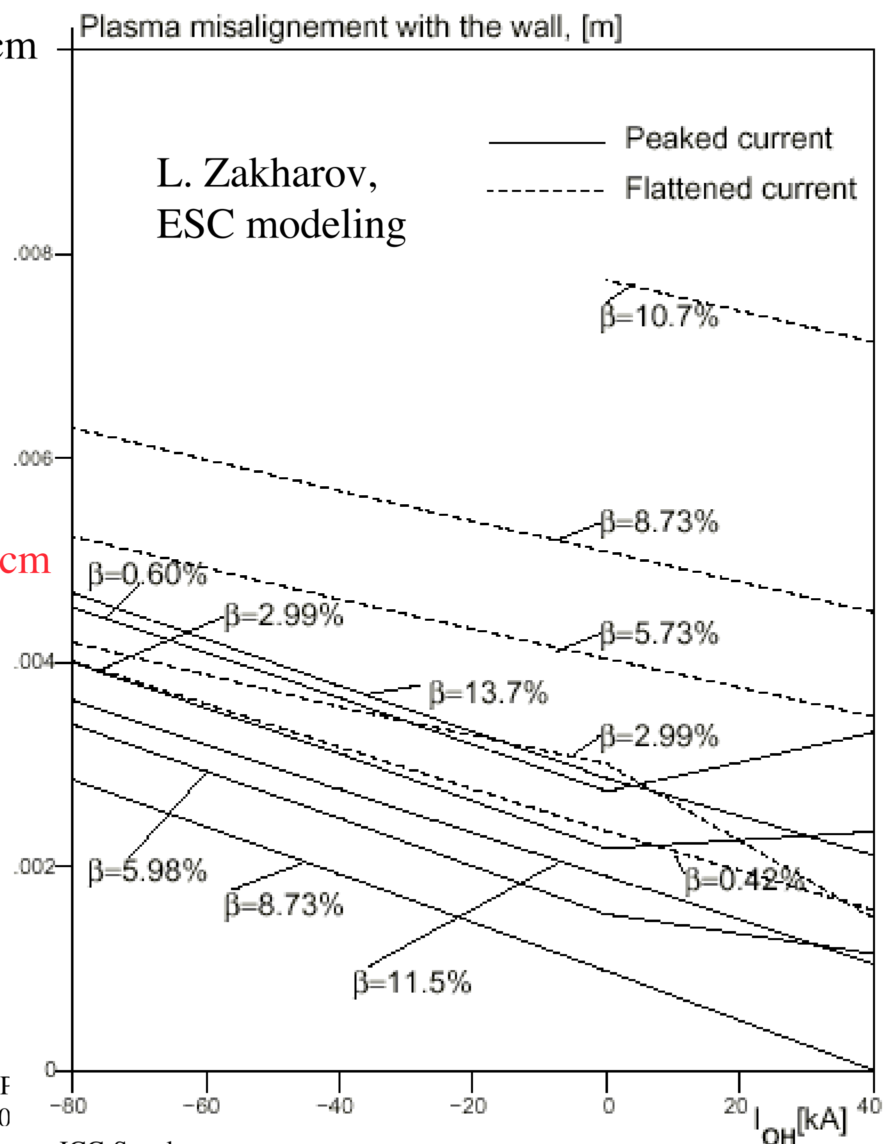
- A “DHD” is a discrete high pressure gas “bubble” which is ionized just inside the LCFS on the high-field side
- Electrons are immediately heated; expands until $\beta \sim 1$
- Accelerated towards the LFS
- Deposits particles <u>and</u> energy in the core
  - Low recycling discharge with peaked temperature
- Enhances τ_E (14 msec in this ASTRA simulation).

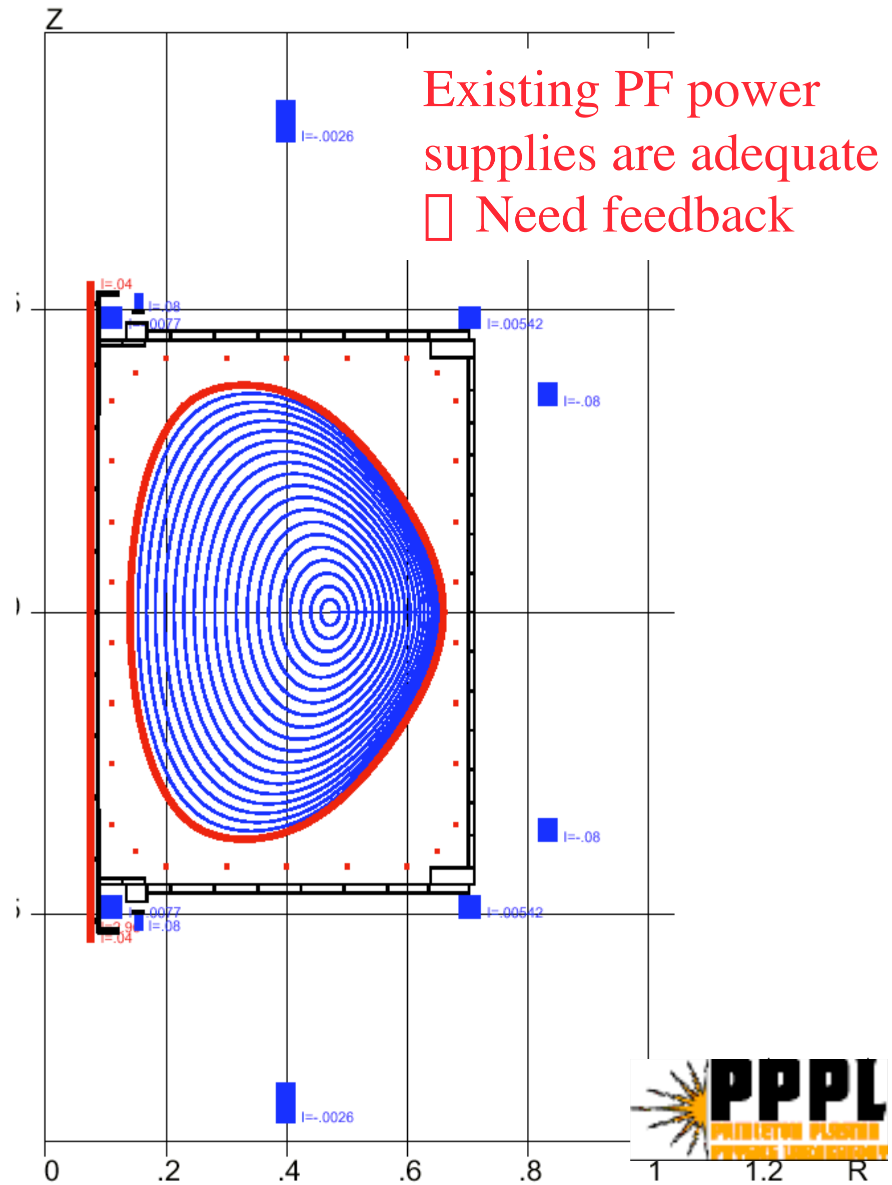


Poloidal field coil set designed for good alignment with shell over wide range of equilibria

1 cm

0.5 cm

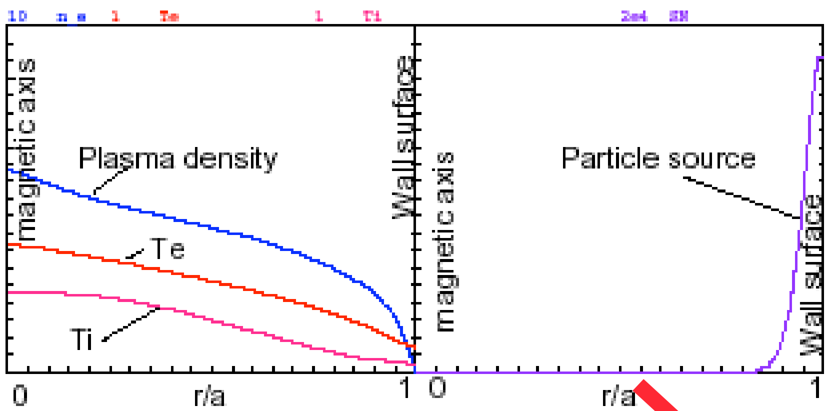




Existing PF power supplies are adequate
 Need feedback

LTX and transport

1 keV
10^{20} m^{-3}



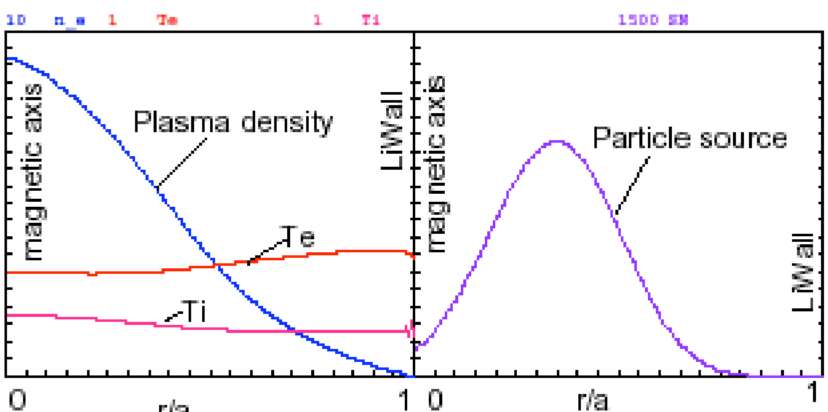
- No edge source for particle transport studies
  - Pellet + jet sources permit wide variation in fueling profile
- Pulsed ECH for □$_e$ studies in absence of □T_e

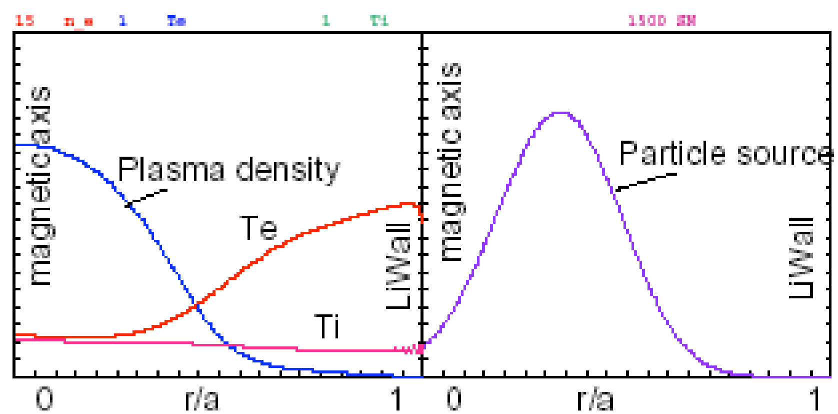
Ohkawa: transport ~1/n

OR:

Merezhkin-Mukhovatov: $1/(n+n_0/4)$

or something else?





ASTRA modeling

Nearly ALL of the issues for a lithium-walled component test facility (CTF) will be addressed in LTX

Issue	Relevant to:	Addressed in:
Recycling on lithium	PE, CTF, reactor	CDX-U, PISCES-B, T11-M, **LTX**
Temperature profiles in low recycling regime	PE, CTF, reactor	**LTX**
Fueling in low recycling regime	PE, CTF, reactor	**LTX,** CDX-U
Particle transport with core fueling, no recycling	PE, CTF, reactor, ALL tokamaks/STs	**LTX**
Lithium sputtering/influx	PE, CTF, reactor	CDX-U, **LTX**
Confinement with novel fueling (DHD), core heating	PE, CTF, reactor	**LTX**
Helium pumping	CTF(?), reactor	FLIRE, other?
Stability of bulk liquid lithium to MHD forces	Reactor	CDX-U, tests possible but not planned in **LTX**
MHD drive of liquid lithium PFC	Reactor	LIMITS (SNL), MTOR (UCLA), FLIRE
Stability of MHD driven lithium film in a tokamak	Reactor	Biggie. Requires a dedicated facility.
Is this worth it?	All	**LTX**

Summary

- Advantages of a Lithium Tokamak Reactor:
  - Compact
    - » High beta, high wall loading
  - Simple
    - » Circular or moderate D-shaped TF coils
    - » Low tech fueling, no current drive,...
  - Very low activation
  - Minimal in-vessel maintenance
    - » Self-renewing first wall
- Development path is comparatively short, low cost
  - It's a tokamak. We know about tokamaks.
  - Coated plate technology will work through the CTF
- Validity of approach is strongly supported by present experiments
- The LTX program has been funded to begin this fiscal year